

**Blue Ribbon Review
of the
TMD Lethality Program
and
Chemical and Biological Warheads**

December 14, 1992

Prepared for:
Defense Nuclear Agency under Contract Number DNA001-88-C-0046

I. Introduction

At the request of Dr. George Ullrich, Deputy Director of the Defense Nuclear Agency, a "Blue Ribbon Review" of the TMD Lethality Program was initiated in January of 1992. A group of consultants was assembled by Logicon RDA under their SETA Contract Number DNA001-88-C-0046 to perform the review. The group included:

Dr. George Abrahamson
Chief Scientist, United States Air Force

Dr. Wallace Deen
Central Intelligence Agency (ret.)

Dr. Arlen Field
Kaman Sciences Corporation

Dr. Milt Gillespie
Los Alamos National Laboratory

Dr. David Huxsoll
Louisiana State University

Dr. Cyrus Knowles
JAYCOR

Mr. Ken Kreyenhagen
California Research & Technology, Inc.

Dr. Joshua Lederberg
The Rockefeller University

Major General Peter Olenchuk
U.S. Army (ret.)

Dr. Michael Frankel of the Defense Nuclear Agency acted as the Government Coordinator, and Mr. Kreyenhagen of CRT acted as the Technical Coordinator of this project. Dr. David Gakenheimer of Logicon RDA acted as the Executive Secretary, and he and Mr. Kreyenhagen compiled this report. Biographical sketches of all of these people are given at the end of this report.

The review was initiated by having the team of consultants attend the TMD part of the LTH-5 Semi-Annual Review Meeting at Fort Bliss on March 2 and 3, 1992. Subsequent to that, a series of topical meetings was organized to address specific subjects requested by the consultants. In particular, the following meetings were held:

April 20 and 21, 1992 at DNA Headquarters

ABO Threat Overview, Sharon Watson, AFMIC
TMD Program Overview, Maj. Ken Bradley, DNA/SPSP
Bulk Chemical Breakup, Norm Banks, SAIC

May 7, 1992 at Battelle

Plans for Biological Warhead Lethality Program,
Carl Alexander & staff, BCL

June 18 and 19, 1992 at Kaman Sciences (Huntsville, AL)

TMD Threat Overview, Jim Foshee, DIA/MSIC
Chemical Warhead Program Overview, Bob Becker, USASDC
Sled Tests, Steve Mullins, TBE
Hydrocode Calculations, Nasit Ari, KSC
ABO Warhead Structural Breakup, Ed Rush, KSC
Live Agent Tests Discussion, Bob Becker, USASDC
TMD Assessment, Julius Lilly, USASDC
Kill Criteria Development, Richard Jackson, KSC
Impact Damage Models, Jeffrey Elder, KSC
TMD Systems Lethality Assessment, Becky Scrip, MEVATEC
Atmospheric Dispersal, Julius Lilly, USASDC &
Steve Diehl, KSC

October 6 and 7, 1992 at Logicon RDA (Washington, D.C.)

Closed working session

In this report, we present the technical and programmatic issues identified by the consultants and their recommendations to address these issues. The next section under this tab is a summary of the issues and recommendations from the entire team of consultants as prepared by Dr. Gakenheimer and Mr. Kreyenhagen for the convenience of the readers. The individual positions of the consultants, which in some cases have a different emphasis than the summary, are presented in the remainder of this report.

The consultants only had time to review the parts of the TMD Lethality Program that pertain to chemical and biological warhead threats carried by ballistic missiles. There are other theater missile threats, including nuclear warheads, HE warheads, and various warheads carried by cruise missiles. Lethality against these threats is of equal (or possibly more) importance, and involves some different phenomenology. Tasks addressing these threats should be reviewed in the future. (Note, for example, that low-flying cruise missiles may actually be the preferred way of delivering chemical and biological agents.)

The budget for the TMD Lethality Program has been ramping up very quickly from about \$1.0 million in FY90 to \$27.0 million in FY92, and the biological part of the program just got started in FY92. As a result, the program has been changing very rapidly, and some of the consultants' ideas have already been implemented or will be before this report is distributed. As another consequence of the rapidly evolving program, new data are coming in weekly which could modify some of the consultants' recommendations. In addition, we understand that some lethality work may be ongoing in the interceptor development programs themselves. The consultants did not review this work, nor work being funded by SDIO overseas.

II. Summary of Issues and Recommendations

1. The fundamental objectives of the program are not clearly defined. The TMD lethality program needs to have three objectives:

- o Support of TMD systems by quantifying lethal effects of particular kill mechanisms against expected threats (e.g., impacts of hit-to-kill vehicles into threat warheads at different velocities).
- o Build longer range technical base needed for lethality assessments against undefined future threats.
- o Provide independent assessments of the effectiveness of interceptor systems.

It appears that **only the first of these objectives is presently being addressed by the DNA program.** This narrow focus may reflect influence from the current system developers. However, defense against ballistic and cruise missiles is a long term issue that should involve a broad range of potential (but realistic) threats and innovative interceptor warhead technologies to defeat them.

Recommendation 1a: In coordination with SDIO, a clearer set of objectives needs to be established for DNA's TMD Lethality Program. These objectives should meet the requirements of TMD systems, and should also provide methodologies and a technical foundation for lethality assessments against a full range of potential threats. DNA should position itself as the lethality technology leader.

2. The program plan would be much stronger if it were based on system analyses and sensitivity studies to define critical issues. We did not see a list of interceptor performance/design constraints and tradeoffs to be considered (i.e., intercept altitude, impact velocity and mass, etc.), nor a list of the critical lethality issues being addressed, nor a list of program tasks with their rationale and technical interconnection. (We did see a very complicated flow chart of program elements from SDIO, but it lacks the rationale for the efforts.) It may be that the existing program plan reflects good intuition about what is important, but system analyses and sensitivity studies are needed, **especially at this relatively early stage in the program,** to define which of the lethality uncertainties are of major importance to systems. It is also unclear how this program interfaces with the systems development programs. Are those programs relying on the DNA program for lethality data and assistance in evaluating various warhead options, or are they doing their own lethality programs in parallel?

Recommendation 2a: Develop a more complete program plan with clear objectives, tasks, and well-defined products. This development should involve system analyses and sensitivity studies to help identify and prioritize the critical lethality issues. This planning should also involve interfaces with the interceptor developers and architectural studies for the system analyses and definition of interceptor performance/design constraints and tradeoffs. There should be short term products such as assessments of specific interceptor warheads against specific targets using "best estimates" for all the input parameters with error bars. There should also be longer term technology products, like comprehensive assessment tools which allow analyses of a range of possible threat designs and interceptor designs.

Recommendation 2b: A crisp briefing package should be prepared for the Task Manager to describe his program, and a Technical Requirements Document (TRD) should be written for distribution to all the program participants and users of the data.

3. The TMD lethality program is relatively large and complex, involving a number of disparate technical disciplines and program elements. By comparison with other technical programs at DNA, the staff which is responsible for the TMD lethality program is quite limited and spread very thin.

Recommendation 3a: Enlarge the in-house staff at DNA to assist the TMD Lethality Task Manager in managing this highly complex, multi-faceted program. Provide him personnel with expertise in all the major technical areas important to this program including the chemical and biological areas as well as shock physics.

4. Past work on ABOs is not being used as much as it should be in the BW part of the lethality program. The U.S. had a biological weapons program from 1943 to 1969, and a number of different bomblets were designed using different materials (e.g., aluminum, steel and plastic) and different dispersal techniques (forced and natural). Although only a few of these designs ever reached production, prototypes of many of the others were tested successfully and their designs are in the archives. These designs should be considered in the lethality program (see threat issue below).

In addition, simulants were developed for many of the ABOs and deployed safely outdoors as part of threat definition and detection programs. At the end of the U.S. offensive program, methods were developed to destroy the ABOs in storage. This information could be very useful in planning lethality experiments on ABO warheads. There is no evidence that this past experience is being used in the present program.

Further, chemical and physical properties of many of the agents and simulants are available along with information on atmospheric transport and degradation as well as information on shock effects from burster charges used to break the bomblets open and disperse the agents. This information could also be very useful to the lethality program.

Recommendation 4a: Task the Chemical Warfare/Chemical and Biological Defense Information Analysis Center (CBIAC), or some other similar organization, to collect, critique, organize and assemble for distribution to the program participants the past data on biological weapons that may be of use to the lethality program. The archives at Fort Detrick, Dugway, and other facilities used for biological weapons development should be searched inasmuch as a lot of past biological work is not in the DTIC system because it had restricted distribution. The same kind of literature search should be done for chemical weapons, if it has not already been done.

5. The need for testing with real biological agents has not been demonstrated. "Live" simulants for pathogens, with very similar chemical and physical properties, have been developed under past programs. Pending the completion of sensitivity studies to evaluate the effects of uncertainties and variations in properties, these simulants can be used in lethality experiments.

The variations in the response of different strains of specific agents to different stimuli will in many cases be as large as the variations between an agent and its simulant. TMD lethality should not depend on subtle variations in properties.

Shock propagation properties of biological agents are potentially important to assessing lethality of kinetic energy kill devices, since these properties will determine the pressure-time histories and temperature-time histories to which agents will be exposed, and also the depth to which shocks propagate into a mass of agent. Measurements of shock Hugoniot relationships can be undertaken to define the shock propagation properties of agents. However, such properties are likely to be dominated by the packing density of the agents (i.e., whether they are dry, very porous powders or in water). In addition, the uncertainties associated with shock propagation through the agent in one submunition may be dominated by the uncertainties associated with shock propagation from one submunition to another and through a cluster of submunitions.

Neutralization of biological agents may not be critical if the threat warheads are intercepted, broken up and the agents aerosolized and dispersed at sufficiently high altitudes (15 km or greater) so the agents become diluted and never reach the ground

in harmful concentrations and/or stay aloft long enough (days to weeks) to be destroyed by ultraviolet radiation. Neutralization is more likely to be important in low-altitude intercepts of cruise missile threats and, possibly, in the case of missile-based threats, if microencapsulation is employed to afford protection against ultraviolet radiation. Small-scale laboratory experiments on real agents may eventually be required to address some of the neutralization issues, but a clearer plan and rationale for them is needed.

Finally, simulants are not as well known for toxins. However, we do not have any reason to believe that acceptable simulants cannot be found for the lethality program.

Recommendation 5a: Compare the physical, thermal, chemical, and biological properties (and their natural variations) of real agents (pathogens and toxins) with simulants. Conduct sensitivity studies to identify the properties of importance to lethality, and to assess the consequences on lethality of uncertainties in the properties and of variations in the properties between different strains of agents and between agents and their simulants. Specific sensitivity studies on shock Hugoniot properties should be conducted taking into consideration various agent packing densities and different submunition designs and stackups inside the warhead.

Recommendation 5b: Pending examination of the relevant properties of agents and available simulants and the sensitivity studies, develop plans for lethality tests which use only simulants. Defer plans for tests with real agents until a strong need is identified and documented. Evaluation of the adequacy of simulants for the lethality program will require consideration of microbiology, physical and atmospheric chemistry, and shock physics.

We understand that the Army, under direction from SDIO, has changed plans and decided not to conduct tests with real biological agents at the present time. We are pleased that the real agent testing has been deferred until the appropriate sensitivity studies can be conducted to justify it.

Early in the review we heard preliminary plans for measuring shock Hugoniot on live agents using small lenticular samples. This is a very difficult measurement, particularly in very porous materials. If there is a need for such measurements, in either real agents or simulants, DNA should employ people who have the experience to make these types of measurements. The experimental and data analysis plans should be carefully reviewed.

Recommendation 5c: With the results of the simulant survey, sensitivity studies and programmatic implications in hand, request the National Academy of Sciences to review the ABO lethality program and to comment on whether real agent testing is needed, and if so, at what stage of the program.

Editorial Note: Two of the Blue Ribbon Consultants had other views of the need for tests with real biological agents. Dr. Knowles expressed concern as to whether all the critical lethality issues could be resolved with simulants and he recommended doing a few tests with real agents early in the program.

Dr. Lederberg did not attend the meeting at Battelle where the plans for the ABO part of the lethality program were reviewed. He did subsequently review this report and said that he concurred with it in every detail on which he is an expert, although he cautioned that (1) relevant parameters on real agents should and can be carefully measured in small laboratory scale experiments; (2) there are some underlying assumptions about the decay of biological agents in the atmosphere that are not well understood; (3) we must also consider scenarios in which attacks are made at night or in heavy overcast; and (4) we should consider the microencapsulation of biological agents to afford them UV-protection.

The reader should refer to Dr. Knowles' and Dr. Lederberg's write-ups later in this report.

6. The lethality program should not rely on a small number of specific CW and BW threat designs. While there are difficult problems in weaponizing chemical and biological agents for theater ballistic missiles, a number of countries appear to be capable of such achievements (or they could acquire the capability from other countries). Designers of chemical and biological warheads have a number of practical options for weaponization; the lethality program needs to consider the full range of such options.

The CW submunition warhead presently being used in the lethality program is derived from an HE submunition where the HE is replaced with a chemical agent. This is certainly a possible design option, but as a chemical submunition it seems grossly overdesigned and it may not be the optimum way of delivering chemical agents. The lethality program (and the modeling methodologies which are being developed) should not rely only on this one very hard design, but should look at a range of designs so the system developers have information on how threat hardness trades off with threat effectiveness.

Recommendation 6a: Develop a set of reasonably-engineered generic point designs for chemical and biological warheads (and for HE and nuclear warheads if they do not exist) using whatever information exists about foreign designs and considering past U.S. designs as possible options since a foreign adversary may have gotten them and since the engineering details are readily available. Consider newer materials and processes that may be available now to a foreign adversary. Bracket the uncertainties with these designs.

Recommendation 6b: Investigate simple countermeasures that an adversary might employ against our interceptor missile systems and quantify the associated penalties for him. Both operational changes and material/structural hardening should be considered.

Recommendation 6c: As a part of the lethality assessment (see next item), assess the relative hardness of all the different types of threat TMD warheads and the systems implications to our interceptor programs, taking into account the range of design options for each type of threat and the associated uncertainties and possible countermeasures. Use these results to help prioritize the TMD lethality research in terms of which threats are most important.

7. The TMD lethality assessment conducted to date is incomplete. Only a few warhead designs have been analyzed (HE/Chem Submunition, Unitary Chem, and Unitary HE). No error bars have been employed on the failure models. The assessment is heavily systems oriented without a lot of target interaction and target response physics modeled. A more complete assessment (or sensitivity study) is needed to help plan the lethality program.

Recommendation 7a: DNA should conduct a comprehensive first-order lethality assessment against all the TMD targets of interest (with HE, chemical, biological and nuclear warheads) using best estimates of the target descriptions and the failure models. Emphasis should be on the target interaction and target response physics and what it takes to destroy the targets with high confidence. The latter needs definition to conduct the study. Sensitivity studies should be conducted as a part of the assessment to establish the importance of uncertainties in target descriptions, target interaction models and target response models. The impact of various kill criteria, simple target countermeasures and interceptor system constraints should be analyzed. The output of this assessment/sensitivity study should be a prioritized list of threat drivers and lethality issues for the program to focus on. The assessment should be redone periodically as more data become available.

The sensitivity study referred to here as part of the assessment is essentially the same one referred to in item 2 above. It may be possible to conduct parts of the sensitivity study separately from the assessment, but many of the same target interaction models and target response models are needed in both studies.

8. Large-scale, complex experiments, which appear to be a dominant part of the current program, will not by themselves provide an adequate basis for good lethality assessments. Such tests provide relevant demonstrations and also provide an opportunity to observe interactions between complex phenomenology, particularly in warheads containing submunitions. However, there is no way to generalize the results of the necessarily few large-scale experiments conducted to date and those planned for the future. This is particularly important since there are a large number of threat target variations that need to be considered as well as many interceptor warhead options.

Recommendation 8a: In addition to large-scale tests, conduct simpler, highly-instrumented component tests (on individual submunitions and clusters of submunitions) to understand failure processes and develop failure criteria and failure models.

Recommendation 8b: Place more emphasis on instrumenting intermediate processes in the large-scale experiments. It is not sufficient to pick up the pieces and count the surviving submunitions; we need to understand the processes which produced failure and the factors which were responsible for survival of some submunitions.

9. Model development is emphasizing very large and complex hydrocode solutions that attempt to include all the interceptor-target warhead interactions. The initial attempts are impressive, although there are concerns as to whether the failure mechanism of the individual submunitions is correct and whether the codes have been adequately validated. Since large-scale testing cannot cover any but a small fraction of the targets and impact conditions of interest, hydrocodes are going to be needed to perform sensitivity studies and to provide additional data to be used with the test data for developing algorithms for the lethality assessments.

Recommendation 9a: Place more emphasis on analyses of individual submunition failure and shock propagation through arrays of submunitions. Develop engineering models and failure criteria using data from simple experiments (Recommendation 8a) and validate hydrocodes with data from the simple experiments prior to analyzing complex targets.

Recommendation 9b: Build on local response models to predict the response of large, complex targets. Consider using different models in different zones of the target and analyzing these zones separately (e.g., direct impact zone versus surrounding structure). Validate codes using data from instrumentation on intermediate processes as well as from final damage configuration.

Recommendation 9c: Implement and maintain parallel modeling efforts with organizations that have strong engineering mechanics capabilities as well as the required numerical capabilities. Conduct frequent working groups with all modelers and basic experimenters present. For the time being, de-emphasize "shoot offs" where competing groups predict isolated results of large comprehensive tests.

Recommendation 9d: Carefully coordinate the modeling and testing efforts. Modelers should have a major input to the test matrices and instrumentation plans.

10. The DNA lethality program does not appear to be looking at advanced (innovative) interceptor kill mechanisms. Rods have shown promise over chunky fragments; more work on them is needed. Neutralizing chemical agents has shown promise, but penetration and mixing are issues that need work.

Recommendation 10a: Invest some resources in investigating advanced/innovative kill mechanisms. For example, consider two stage warheads where the first stage is used for target penetration and breakup and the second stage is used for agent neutralization. DNA should become the leader for kinetic-energy lethality technology development.

11. Atmospheric agent dispersal analyses to date have not been very useful. For example, calculations have been done for ABO warhead breakup at low altitudes below normal submunition deployment, and incorrect particle sizes have been used for the agents. The presenter of this work claimed these cases were run to test all the physics in his code, but valuable time is being wasted and some of the earth boundary layer physics being considered may not even be important to the TMD lethality problem involving missile-based threats. (Note, it could be important to low-altitude cruise-missile-based threats.)

Recommendation 11a: Focus atmospheric dispersal analyses for missile threats on high altitude intercepts (prior to submunition deployment). Consider, on a statistical basis, a range of atmospheric conditions for geographical areas of interest and include atmospheric degradation as well as dispersal. Determine intercept requirements for high confidence of safe concentrations

on the ground. Consider various target breakup conditions to determine sensitivity on ground concentrations. Evaluate the importance of a small number of surviving or partially damaged submunitions.

Recommendation 11b: Investigate the utility of providing equivalent risk-dose maps for a range of hypothetical chemical or ABO attacks, using historical wind data (perhaps by season) for the specific areas of interest. Also investigate the utility of a quick look reaction capability to assess the implications of a specific attack on a given day. DNA should talk to FEMA and others about a cooperative program to update the civil defense aspects of a chemical/ABO attack.

Recommendation 11c: Draw upon DNA expertise in high-altitude nuclear cloud modeling (see next item) to strengthen the chemical and biological dispersal work.

Editorial Note: The Army has recently established a working group to address the chemical/ABO atmospheric dispersal problem. The Blue Ribbon Review Consultants were not briefed on the plans and progress of this group. The recommendations above are based on one topical presentation and the LTH-5 Semi-Annual Program Review of March 2 and 3, 1992. The consultants believe that this program area should be reviewed further in the near future.

12. There is considerable synergism between the TMD lethality research and other DNA activities. For example, the work on dispersal of hazardous materials in the atmosphere is similar to the advection and diffusion of nuclear fallout and it is related to a companion program recently begun at DNA concerning collateral effects from targeting chemical and biological storage and manufacturing facilities. Similarly, the modeling of interceptor penetration, target breakup, etc. is similar to the dynamic modeling of structures, RVs, etc. that DNA has worked on for years. Unfortunately, there does not seem to be much of a connection between previous related nuclear effects work at DNA and the TMD Lethality Program. Certainly a fresh start with new people might create new insight, but some connection to past efforts seems worthwhile. With the schedule and budget constraints on the TMD Lethality Program, it would be very helpful to transfer any expertise that exists in other program areas to this one. The other related DNA projects might as well benefit from a better understanding of what is being done under the TMD Lethality Program.

Recommendation 12a: Invite the relevant CTMs from related DNA programs to participate in the next program review. Encourage them to actively participate in the formulation of the TMD Lethality Program.

13. No work is being done on kill assessment related to TMD. The requirements for kill assessment are less clear for TMD than for strategic defense since the time lines are shorter and the opportunities for second shots may be less. In addition, submunitions make kill assessment a harder problem for TMD than for strategic applications.

Recommendation 13a: Investigate architecture studies to establish whether kill assessment has a role in TMD. If so, investigate possible approaches for doing kill assessment and begin collecting relevant data in ground experiments.

14. A conventional type interceptor may not be able to defeat all possible TMD warheads with high confidence. Killing a large number of chemical or biological submunitions in one warhead could be very difficult and may end up involving low confidence.

Recommendation 14a: As a backup option, we agree with DNA's decision to investigate the potential lethality of a low-yield nuclear interceptor against TMD warheads, assuming that if all else fails, a nuclear response to a chemical or biological threat would be considered acceptable.

15. Any type of lethality program involving biological warheads, even using just simulants, must be reported now under the confidence building measures of the 1972 Biological Weapons Convention. Failure to report this work could complicate discussions with the Russians over reporting their past biological programs. Public knowledge of our defensive programs should be a deterrent to the proliferation of biological weapons.

Recommendation 15a: Coordinate with SDIO over who should report the SDIO funded biological lethality work. The DNA funded work on nuclear interceptors should probably be reported separately.

Drs. Huxsoll and Gakenheimer prepared a separate report on treaty considerations for testing biological defenses that shows the type of material the U.S. has been reporting in April of each year.